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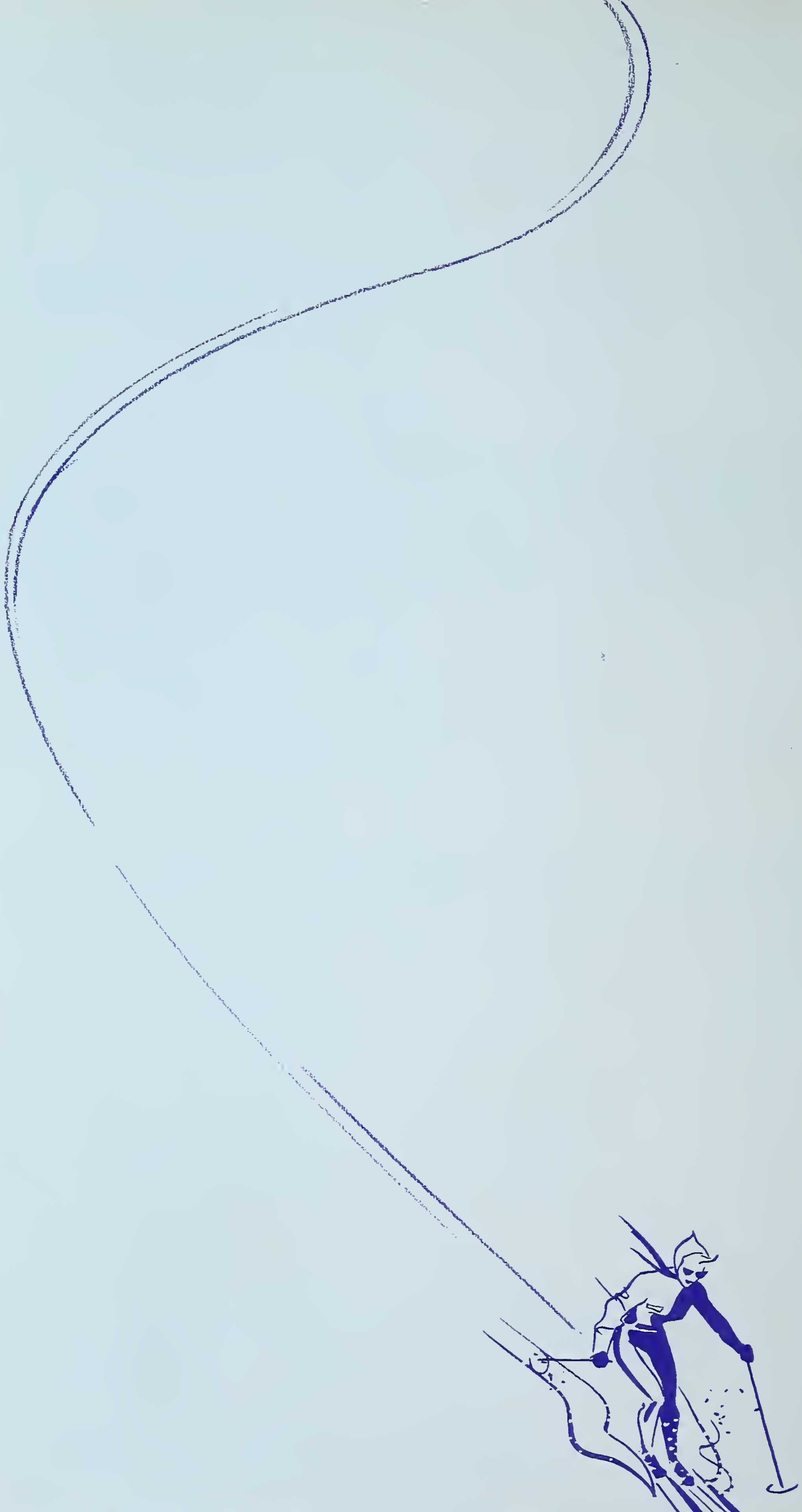

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THE EFFECT OF SPIRAL GRAIN ON POLE TWIST AND BENDING STRENGTH

David P. Lowery
and
E. C. O. Erickson

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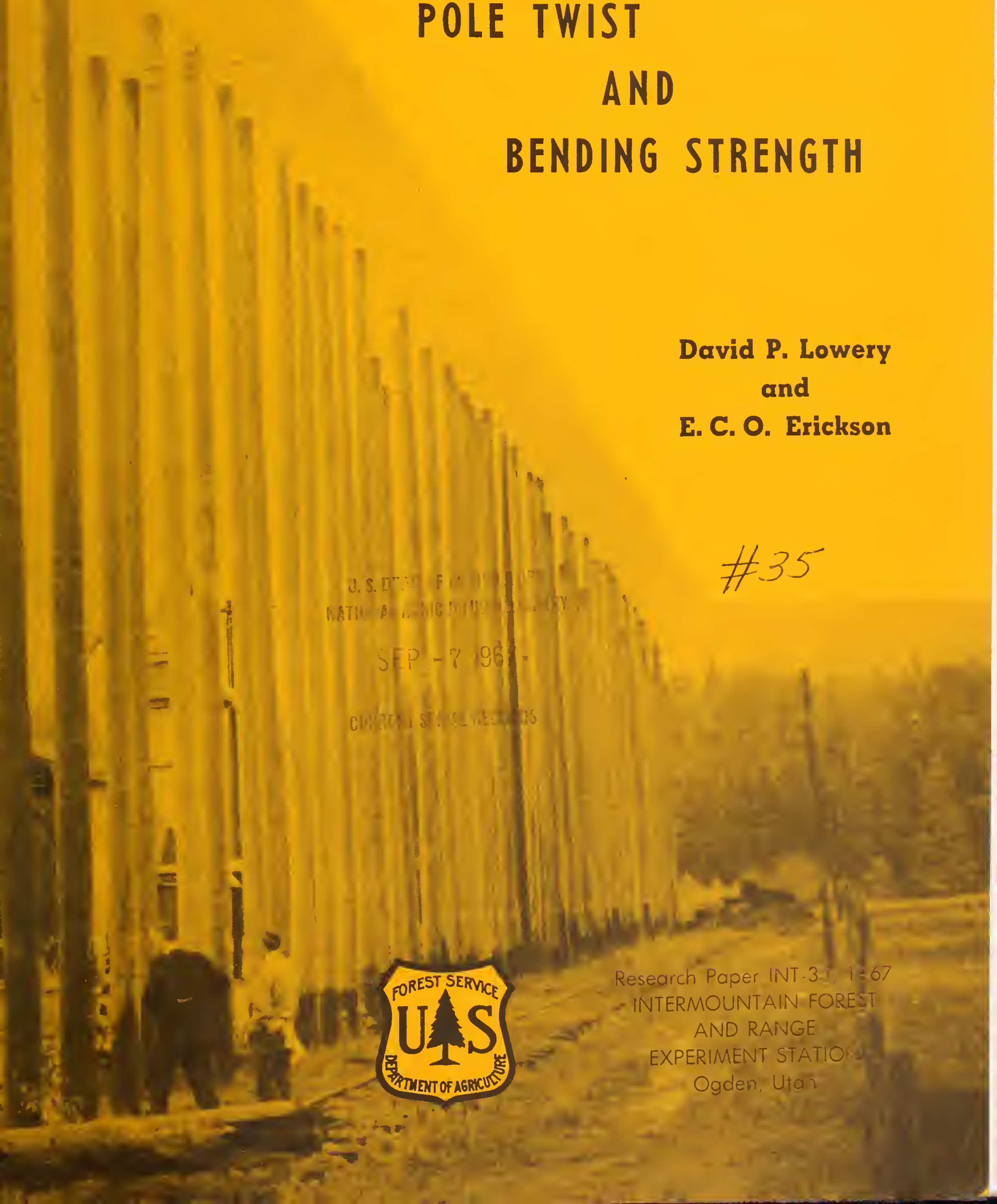

Research Paper INT-35, 1967
INTERMOUNTAIN FOREST
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EXPERIMENT STATION
Ogden, Utah

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COVER PHOTO:

Experimental setup for study of twist of spiral-grained poles in use. (See drawing on page 3)

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by

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THE EFFECT OF SPIRAL GRAIN ON POLE TWIST AND BENDING STRENGTH

David P. Lowery and E. C. O. Erickson

Spiral grain and its effect on the twisting of poles in service have been under investigation by the Intermountain Forest and Range Experiment Station for a number of years. Earlier studies have been concerned with the detection of spiral grain in standing trees, the inspection of poles in transmission lines and pole yards, and the effect of spiral grain on the performance of poles. The present study was designed mainly to determine how spiral grain, in combination with other characteristics, affects the twisting of three species of poles in service. One corollary study explored the value of particular characteristics and treatments of poles in preventing twist. Another tested the bending strength of a limited number of spiral-grained poles. General observations on the nature of spiral grain were made from laboratory examination of pole cross sections.

LITERATURE REVIEW

Although the literature abounds with references to spiral grain, in many instances this characteristic is noted as an oddity. However, in reports published in 1925 and later, Champion (5, 6, 7)[1] established that spiral grain is a genetic trait, transmitted from parent to progeny. On the basis of observations and studies made in Canada, Northcott (12) advanced the hypothesis that spiral grain is the normal growth habit of trees. Rudinsky and Vité (14) have described five water conduction systems in conifers, of which spiral grain is a feature in three.

Elliott, alone and also in conjunction with Kennedy, studied spiral grain in Douglas-fir, western hemlock, and red alder (8, 9). They concluded that the slope of grain in any one tree is not constant; that is, it changes radially, in successive growth rings. Stevens (15) substantiated this finding and reported circumferential and longitudinal changes in spirality. He also devised a formula for calculating the amount of twist developed in the drying of hollow wooden tubes having spiral grain.

It is generally agreed that spiral grain is responsible for twisting of poles in service. The relation between spiral grain and twisting has been studied in simulated service tests by several workers. Burger (4), in Switzerland, found that less twist occurred in right-spiraled and straight-grained poles than in left-spiraled poles. In his study the spruce and silver fir poles had been treated with preservative before debarking. Krogh (10), working with pine and eucalyptus poles in South Africa, reported that fluctuations in twisting in seasoned, treated poles were dependent on the periodic loss and reabsorption of moisture by the wood. Wellner and Lowery,[2] in a study of western larch poles from eastern Washington, verified that pole twist is caused by spiral grain and that loss and absorption of moisture is a controlling factor. In connection with such studies, in which seasoning of poles may be an important element, it is worth noting that Mathewson (11) determined that lodgepole pine poles had an average moisture content of 17 to 19 percent after 1 year of air drying.

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[1] Numbers in parentheses refer to Literature Cited, p. 15.

[2] Wellner, C. A., and D. P. Lowery. Spiral grain--a cause of pole twisting. U.S. Forest Serv., Intermountain Forest and Range Exp. Sta., Ogden, Utah. (Manuscript in preparation)

The effect of spiral grain on the strength of dimensional lumber was studied by Wilson (16) at the U.S. Forest Products Laboratory. He showed that the modulus of rupture--a measure of strength in bending--decreased rapidly as the slope of grain increased. The reduction in bending strength of spiral-grained material as compared with straight-grained material was about 10 percent at a grain slope of 1 in 12 (2° 43") and nearly 20 percent at 1 in 15 (3° 48"). Banks (3) reported that spiral grain affected the strength of pines grown in South Africa; Rault and Marsh (13) studied the silvicultural implications of spiral grain and its effect on converted timber. Wood et al. (18), after extensive tests, recently reported on the strength and related properties of wooden poles. Tests were made of bending strength and other wood properties, using selected treated and untreated poles representing the principal pole species of the United States and Canada.

GENERAL METHOD OF THE STUDY

For use in all three phases of the study, 62 spiral-grained poles were set upright in the ground at Libby, Montana, in September 1955. Forty-eight of the poles were assigned to the main project, the study of twist, and from them a selection was eventually made for the bending-strength study. Fourteen additional poles were used for the study of possible preventive measures.

The poles were specially selected for the purposes of the study, with regard to species, direction of grain slope, degree of grain slope, and moisture condition. Pairs of poles with similar characteristics were chosen, so that the study might have a two-replication base. Every effort was made to match the pairs as closely as possible. (A few exceptions in matching of steepness of grain slope were unavoidable, and do not seriously affect results.) All 62 poles were 40 to 45 feet long and fell in classes 1 to 5; the majority were in class 3 (2).

The poles were prepared in various ways that are described below in the discussion of the particular study for which they were used. Then all were provided with a means for measurement of twist. A hole was drilled, approximately 1 foot from the upper end of each pole, and a 6-foot length of 1-inch pipe, simulating a crossarm, was inserted and attached to the pole. A string (later replaced by piano wire) was fastened to the free end of the pipe and extended to the ground.

The poles were then randomly assigned to a test position and alined in a row, extending due east and west (see fig. 1). The spacing was about 4 feet and the poles were set approximately 5 feet in the ground. An iron rail was positioned parallel to the row of poles and approximately 4 feet from it, so that the crossarm on each pole projected over the rail. To make the initial measurement, a plumb bob was attached to the wire suspended from the crossarm of each pole, and the position of the plumb bob was recorded as a center punch mark on the rail. Later measurements at varying intervals were made in a similar manner, the deviation from the punch mark being measured with the angle-measuring device described by C. A. Wellner (16).

In July 1961, at the completion of the test period, the poles were pulled from the ground and various measurements were made, as will be described later. Ten poles were then selected from the group of 48 for shipment to the U.S. Forest Products Laboratory for bending-strength tests. So that internal slope of grain could be measured, the remaining poles were sectioned. These sections were examined and measured in the laboratory and data were obtained from them which was helpful in the general description of the characteristics of spiral grain.

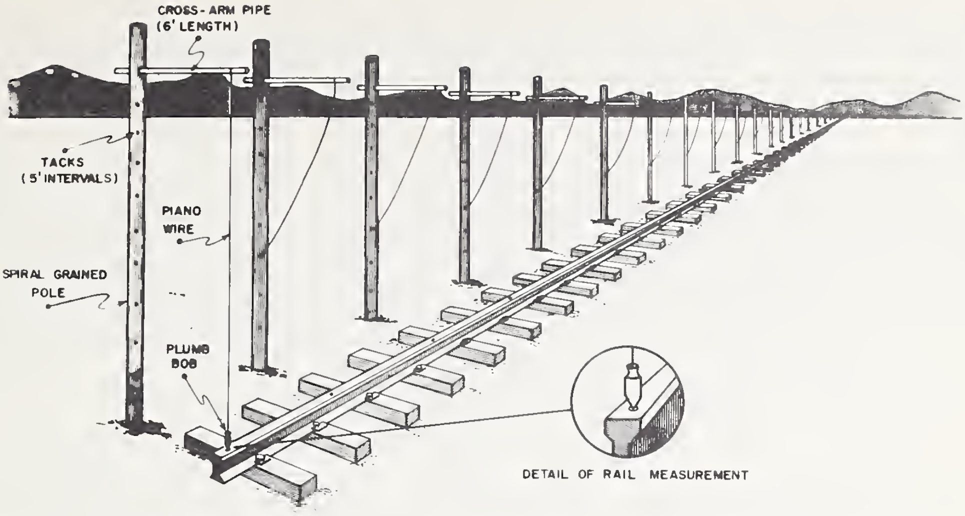

Figure 1.--Arrangement of poles in study of twist of spiral-grained poles in use.

STUDY OF TWIST

Relation of twist to characteristics of poles

As indicated earlier, the 48 poles chosen for the study of twist were selected with the intention of isolating the characteristics that might be related to the amount of twist; that is, species, moisture condition, direction of slope of grain, and degree of slope of grain. Of the 48 poles, 16 were from each of the three principal western pole species--Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), lodgepole pine (*Pinus contorta* Dougl.), and western larch (*Larix occidentalis* Nutt.). Eight of the poles selected for each species had been air seasoned for at least 1 year, and eight were freshly cut or green. In each group of eight at each moisture condition, four poles had a left spiral and four had a right spiral.[3] Each four-pole group was composed of two pairs of poles, one pair having steep slope of grain and one pair having moderate slope of grain. The severity of slope of spiral grain is expressed as the pole length in inches over which there is 1 inch of deviation from the longitudinal axis. The ratio 1:16 thus means 1 inch of deviation in 16 inches of pole length. Steep slope of grain was defined as 1 in 16 or less, and moderate slope as 1 in more than 16. Thus, for every pole of a particular species there existed one approximately matching pole and seven pairs of possible "partners," each differing in one or more of the important characteristics. All poles were butt-treated with creosote.

The data gathered from the measurements made with the plumb bob concerned both the direction and amount of twist. Poles with a left spiral grain tended to twist to the left, and poles with a right spiral grain tended to twist to the right. During the period when observations were made at fairly short intervals, it was evident that some twisting in the reverse direction took place, apparently as a result of seasonal climatic conditions. This twisting was almost always much less than the twist in the prevailing direction.

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[3] Right-hand spiral twists upward to the right and left-hand spiral twists upward to the left, as viewed by a person facing the pole.

The overall measurements showed a steady increase in the amount of twist, up to a point when moisture content of the poles reached equilibrium with the surrounding atmosphere. After equilibrium was reached, the amount of twist varied from the maximum in relation to seasonal variations.

To explore the relationship of the data to the specific characteristics of the various pairs of poles, the data were analyzed statistically; the results are shown in table 1. (For this purpose, direction of twist was disregarded.) The table shows that initial moisture condition of wood, direction of spirality, and grain slope were significantly different at the 1-percent confidence level. Also significant at the 1-percent confidence level were the three-way interaction, species times initial moisture condition times grain direction; and the four-way interaction, species times moisture condition times grain direction times grain slope.

Table 1. --Analysis of variance of data on maximum twist in the major pole study

Source of variation	Degrees of freedom	Sum of squares	Mean square	F test
Replication	1	0.97	0.97	
Species (S)	2	75.82	37.91	1.015
Moisture condition (M)	1	707.64	707.64	**18.941
Direction of grain (D)	1	2,683.53	2,683.53	**71.829
Grain slope (G)	1	1,821.64	1,821.64	**48.739
Interactions:				
S × M	2	150.51	75.26	2.014
S × D	2	54.20	27.10	.725
S × G	2	85.12	42.56	1.139
M × D	1	12.50	12.50	.335
M × G	1	115.63	115.63	3.095
D × G	1	78.79	78.79	2.109
S × M × D	2	327.64	163.82	**4.385
S × M × G	2	106.04	53.02	1.419
S × D × G	2	39.38	19.69	.527
M × D × G	1	2.05	2.05	.055
S × M × D × G	2	295.11	147.56	**3.950
Error	23	859.38	37.36	
Total	47	7,415.95		

**Significant at 1-percent confidence level.

The degree of twist is shown graphically in figures 2 and 3. Since difference of species was found to have little significance, the data for all species were averaged together. Thus each curve on the graph represents six poles, two of each species, having the particular moisture condition or slope of grain indicated. It may be seen from the figures that, in general, poles having left spiral grain twist more than poles with right spiral grain. An apparent exception in this study is the December 1960 observation. Green, right-spiraled poles with steep grain slope had changed slightly more during the period covered than the air-seasoned left-spiraled poles with moderate grain slope. This is understandable, however, in view of the evidence in the graphs that poles that had been air seasoned for at least 1 year twisted less than the matched green poles, and that poles with a moderate slope of grain twisted less than the matched poles with steep grain slope.

To demonstrate the importance of seasoning, the data on degree of twist were graphed from three different starting points (November 1956, October 1957, and April 1958), arbitrarily chosen as points of assumed moisture stability. The curves for the six green trees having left spiral grain are shown in figure 4. These graphs, along with those for the right-spiraled poles, suggest that 2 to 3 years of air seasoning of poles before they are treated and used would markedly reduce the amount of twist developed in service. The need seems clear for a faster seasoning method than that now in general use.

A summary of the data on maximum twist with relation to pole characteristics is given in table 2.

Table 2.--Summary of maximum twist[1] of poles according to direction of spiral grain (left, right), degree of slope of grain (steep, moderate), and moisture condition (air seasoned, green)

	Western larch				Douglas-fir				Lodgepole pine			
	Steep		Moderate		Steep		Moderate		Steep		Moderate	
	Seas.	Green	Seas.	Green	Seas.	Green	Seas.	Green	Seas.	Green	Seas.	Green
	Degrees											
Left	40.1	[2]29.3	18.3	21.9	21.1	43.9	8.0	17.4	17.8	42.3	18.6	21.2
Right	10.6	25.1	3.2	6.4	12.5	18.3	2.9	8.8	8.2	15.5	3.4	6.2

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[1] Each value is the average maximum twist of two similar poles.

[2] The unusual low value for green poles in this instance is apparently attributable to lower specific gravity and less steep slope of grain in this particular pair of poles.

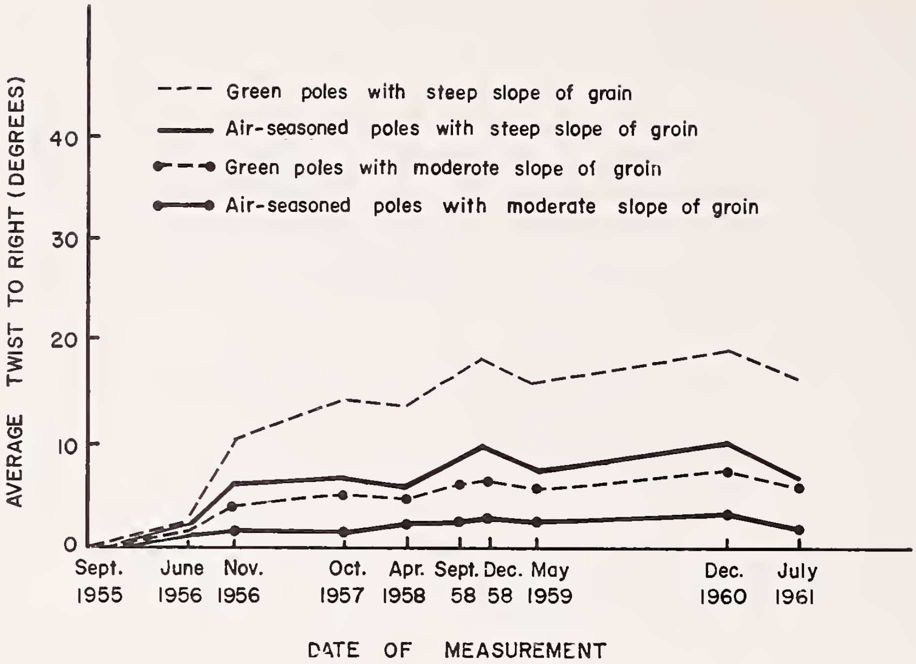

Figure 2.--Average twist of right spiral-grained poles, September 1955-July 1961. Each curve represents six poles, including two of each species studied.

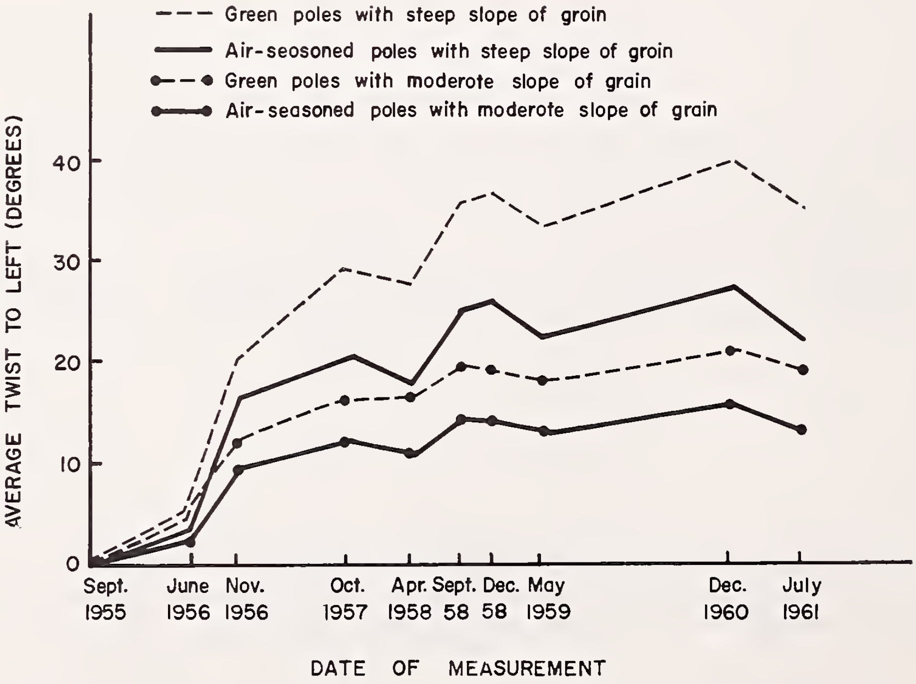

Figure 3.--Average twist of left spiral-grained poles, September 1955-July 1961. Each curve represents six poles, including two of each species studied.

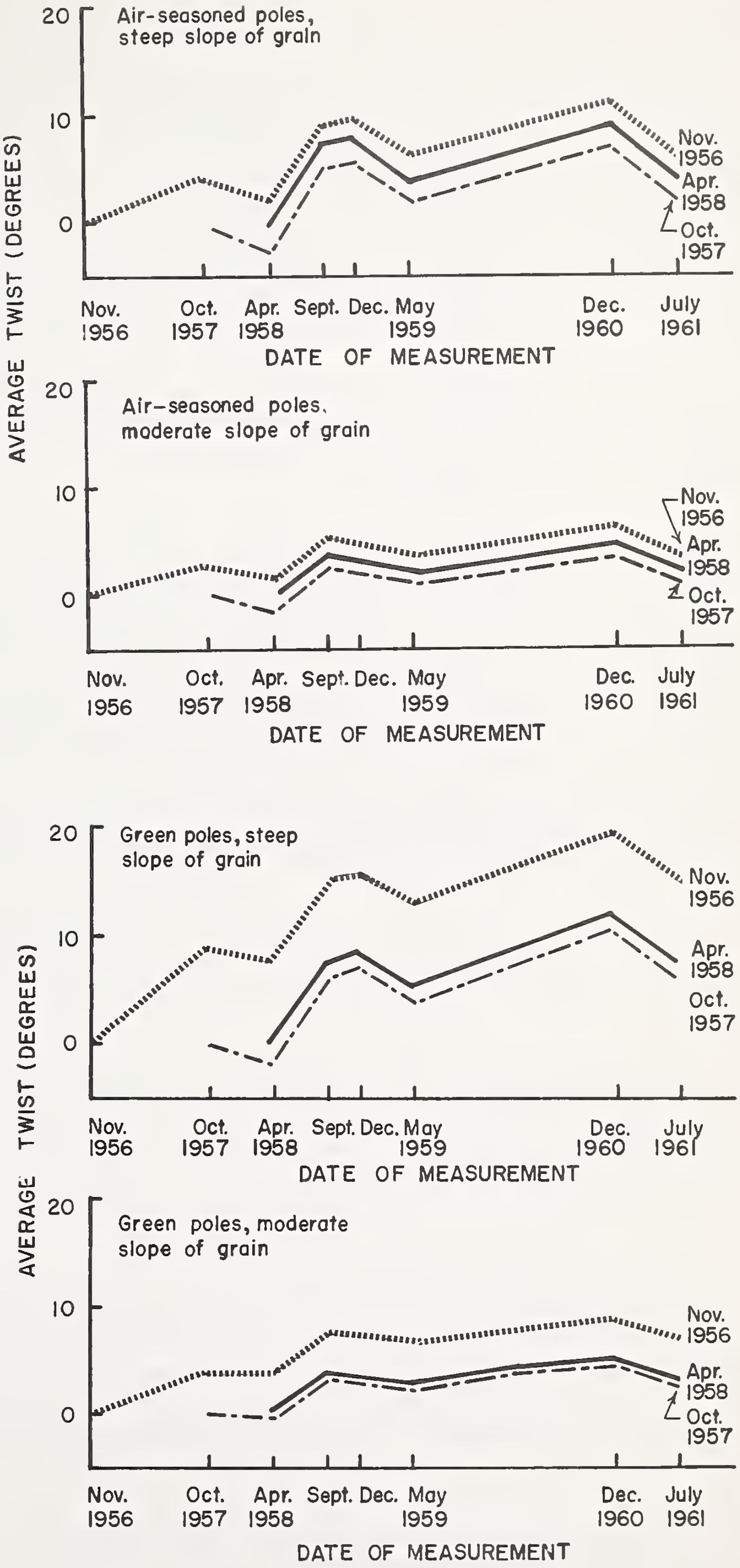

Figure 4.--Average twist of left-spiraled poles, plotted from three different points of assumed moisture stability. Each curve represents six poles, including two of each species studied.

Some Observations on Spiral Grain

The study made possible some useful measurements of spiral grain which cast light on the nature of the phenomenon. Before the 48 poles were set up for the experiment, a longitudinal reference line was drawn on the surface of each pole and tacks were driven at 5-foot intervals along the line, to determine whether one section of the pole twisted more than another. The first tack was placed 18 inches above the assumed groundline. The slope of grain and the pole circumference were determined at the position of each tack. Later, when the poles were taken from the ground, the displacement of the tacks was measured. A guideline was drawn from the tack nearest the butt end to a corresponding point at the other end along the longitudinal axis of the pole, and the tack displacement was measured as the horizontal distance from the line.

In general, displacement of tacks increased gradually but consistently from the bottom to the top of the pole. As expected, total tack displacement was strongly correlated with the maximum twist as measured with the plumb bob; that is, poles that twisted the most had the greatest total tack displacement.

Measurements of circumference were made at each tack position and compared with those made before the poles were set up. All poles decreased in circumference during the test period. The western larch poles decreased in circumference an average of 6.05 inches; Douglas-fir poles decreased an average of 4.40 inches; and lodgepole pine poles decreased an average of 5.06 inches. A statistical analysis of the measurements was made, with the results shown in table 3. The variables of species and initial moisture condition were significantly different at the 1-percent confidence level, and the four-way interaction (species times moisture condition times direction of grain times grain slope) was significant at the 5-percent confidence level. The poles air seasoned 1 year shrank an average of 3.7 inches, whereas the green poles averaged about twice as much shrinkage--6.6 inches. Thus circumferential changes can be correlated in part with the measurements of twist discussed earlier.

Surface slope of grain as measured at each tack position at the beginning and end of the experiment was found to have changed during the test interval. However, the changes were inconsistent and the final average slope of grain did not correlate with data on maximum twist. The average slope of grain decreased in 26 poles, but increased in 22 poles.

So that internal spiral grain could be measured, sections of the poles were examined in the laboratory. Three sections approximately 1 foot long were cut from all but two poles--one section from the center and two approximately 8 feet from the ends. The remaining two poles were completely cut into 1-foot sections. Each section was identified as to pole and position within the pole, and the tack reference line was retraced on each section to aid in reorientation.

In the laboratory, each section was split on a line across the pole from the tack reference line through the pith. The slope of grain at 10-year growth increments was measured on the freshly split face by means of a device similar to that developed at the Canadian Forest Products Laboratory (9).[4] The two poles that were completely sectioned were reassembled in the laboratory and the measurements of slope of grain were made on the same growth rings in all sections. The 10-year rings in the lowest (butt-end) section were used as a base.

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[4] The instrument is essentially a knife edge attached at right angles by a slotted bar to a machinist's protractor. The knife edge is placed on the pith and the protractor is moved to the point or growth ring where the slope of grain is to be measured.

Table 3.--Analysis of variance of total circumferential change[1] in poles in the major pole study

Source of variation	Degrees of freedom	Sum of squares	Mean square	F test
Replications	1	0.01	0.010	0.013
Species (S)	2	22.29	11.145	**15.000
Moisture condition (M)	1	95.49	95.490	**128.520
Direction of grain (D)	1	.68	.680	.915
Grain slope (G)	1	.42	.420	.565
Interactions:				
S × M	2	3.32	1.660	2.234
S × D	2	3.36	1.680	2.264
S × G	2	3.93	1.965	2.645
M × D	1	.98	.980	1.319
M × G	1	.28	.280	.377
D × G	1	.93	.930	1.252
S × M × D	2	3.48	1.740	2.342
S × M × G	2	3.58	1.790	2.409
S × D × G	2	1.02	.510	.686
M × D × G	1	.01	.010	.013
S × M × D × G	2	7.43	3.715	*5.067
Error	23	17.09	.743	
Total	47	164.30		

[1] Each value was based on the total change in 8 measurements of circumference. Seasoning checks and splits were included in the measurements.

**Significant at 1-percent confidence level.

*Significant at 5-percent confidence level.

Examination of internal spiral grain in the laboratory disclosed that the slope of grain is an ever-changing characteristic of wood. The internal slope of grain in the poles (as sampled in the three cross sections of each pole) gradually changed from the pith to the periphery. In general, these data conformed to results reported in other studies (8, 9). In the present study we found a left spiral near the pith; in poles showing right spiral grain at the surface, this gradually decreased in degree to zero and was succeeded by an increasing right spiral. Measurements for almost all sections of right-spiraled poles showed this same change in pattern of slope of grain. (Because height growth varied in the poles sampled, data obtained from the various sections of a given pole were considered independent samples.) Poles with a left slope of grain on the surface were left-spiraled throughout. These observations partly explain the greater torsional stability of right-spiraled poles, as evident in the data on twist. Apparently there is a counterbalancing of shrinkage stresses between the left- and right-spiraled poles, whereas the left-spiraled poles lack this restraint.

Data on longitudinal changes in the slope of grain were obtained from the two poles that were completely sectioned. Individual growth rings were identified and measured in successive sections. These data indicated that the slope of grain in the same growth ring is not constant but varies considerably. The data also disclose that the change from a left to a right spiral occurred in the lower portion of the stem first and gradually progressed up the stem in succeeding growth rings. Thus, both left and right spiral grain may occur within the same growth ring at different heights.

STUDY OF POSSIBLE MEASURES TO PREVENT TWIST

For the secondary study, designed to explore measures that might prevent twisting of poles in service, 14 western larch poles having left spiral grain were selected. The characteristics to be investigated were the relative proportions of sapwood and heartwood, and longitudinal variation in steepness of grain slope; treatments to be tested were capping and preservation with creosote. The 14 poles were therefore selected to include seven matched pairs, as follows: two pairs of heartwood poles, prepared by complete removal of the sapwood in the pole peeler; one pair of poles having a high proportion of sapwood; one pair having a grain slope of 1 in 10 or less in the upper third but 1 in 20 or more in the lower two-thirds; one pair capped with free-fitting covers (inverted metal buckets); and two pairs (one pair air seasoned at least 1 year and one pair green) that had been treated by the full-cell process with coal tar creosote preservative solution. The class of poles varied, but most were class 3 or 4; steepness of slope varied between 1:5 and 1:28, but pairs of poles were generally matched in this respect. Except for the last two pairs, all poles were green and had been butt-treated with creosote when they were set upright for the test.

A summary of the results of the measurements of twist is given in table 4. Statistical comparisons of the data revealed no significant differences among the pairs. Apparently, the characteristics and treatments studied had no effect on the degree of twist.

Table 4.--Maximum twist[1] of selected left spiral-grained western larch poles, 1955-1961

Pole characteristic or treatment	Twist[2] of pole from Sept. 1955 to: Nov. 1956	Oct. 1957	Dec. 1958	May 1959	Dec. 1960	July 1961
	Degrees					
Sapwood removed (class 3)	15.7	36.4	41.9	42.8	48.8	45.4
Sapwood removed (class 4)	9.8	26.7	30.7	31.2	36.4	33.0
High proportion of sapwood	6.2	16.1	18.6	18.3	22.0	18.9
Slope of grain 1:10 or less in upper third	7.3	21.3	24.7	25.6	28.6	26.8
Capped with inverted metal bucket	7.8	24.2	26.4	32.4	37.9	34.5
Air seasoned 1 year, full-length creosote treatment	8.1	17.1	25.3	28.5	35.5	32.6
Green, full-length creosote treatment	5.2	20.1	28.3	28.7	38.2	36.3

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[1] Twist values are averages of measurements made on two similar poles.
[2] All twisting was to the left.

BENDING-STRENGTH STUDY

The 10 spiral-grained poles submitted to the Forest Products Laboratory included 5 Douglas-fir and 5 western larch poles. Three of each species were right-spiraled and 2 were left-spiraled.

Test Procedure

The method of pole testing conformed to the American Society for Testing Materials (ASTM) standard for machine tests (1). Before these poles could be tested, they had to be brought to a uniform moisture condition comparable to that of similar straight-grained poles for which strength values are available (18). Therefore the poles were submerged in water for 10 weeks before the test. Moisture meter readings, taken on several of the poles when they were first removed from the water, were between 22 and 25 percent at a depth of 3 inches below the pole surface. The outer surface of each pole, where test stresses are concentrated, was then assumed to be at or near the fiber saturation point.

So that a uniform dead load for testing poles over a 33-foot span could be maintained, it was necessary to cut the poles to the proper size. Some of the poles were 40 feet long, whereas others were 45 feet long. In order to position the groundline (loading point in test) in untreated material 6 feet from the butt end, a 4-foot section was cut from the butt end of each pole. The poles originally 40 feet long were thus 36 feet long; 4 to 5 feet were then cut from the tip end of each of the poles originally 45 feet long to bring them to the required 36 feet.

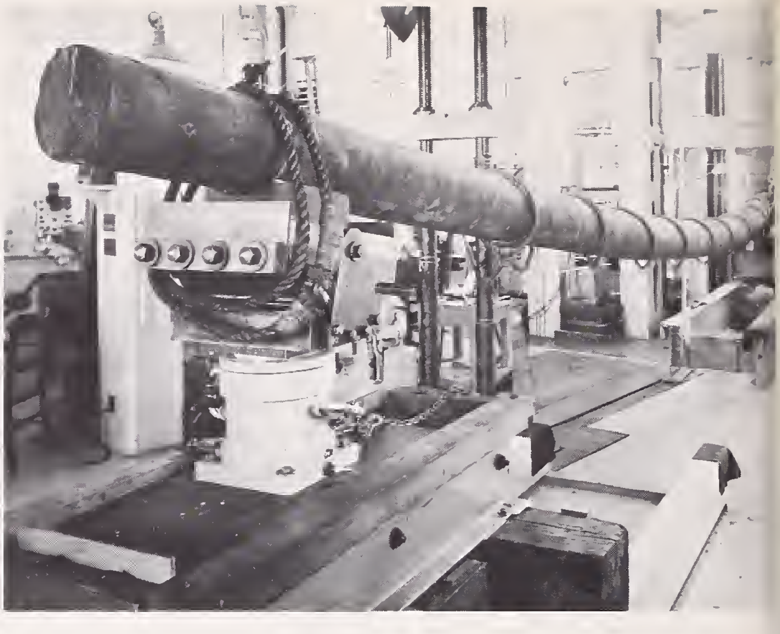
For the test itself, circumference was measured at the butt, tip, and groundline, and at each of the 5-foot intervals where tacks had been driven for the twist study. The poles were weighed at each support point; that is, at points 1 foot and 34 feet from the butt end. Finally, at the time of the test, moisture content was determined at 120-degree intervals around the circumference of the poles at the groundline, using an electric moisture meter. The readings were taken at half-inch increments up to a depth of 2½ inches. The poles were supported at points 1 foot from the butt end and 2 feet from the tip end and were tested over a span of 33 feet. The load point was located 6 feet from the butt and the load was measured by a hydraulic load cell at the tip support point. Suitable rockers and rollers were provided to accommodate the slope of the ends of the pole and the shortening due to curvature as loading progressed. The rate of movement of the loading head was 0.77 inch per minute. The poles were at room temperature at time of test. Figure 5 shows a pole being tested.

Upon completion of the test, the type and location of failures were marked on a sketch of the pole, as well as the size and location of any knots that may have contributed to the failure. A 1-inch thick disk was cut from the pole near the point of failure, for use in determining the specific gravity of the pole.

Results

The test results and other related data for the 10 poles are summarized in table 5. Note that for each pole, a modulus of rupture at load point is given. This figure in itself was not comparable with data for straight-grained poles, as given in the report of the recently completed ASTM Wood Pole Research Program (18). Adjustments were necessary for differences in specific gravity of the poles and to take into account the difference in number of poles tested.

Figure 5.--General view of the machine test arrangement used for spiral-grained poles. The pole shown is stressed to its maximum load.



The modulus-of-rupture values for the spiral-grained poles were adjusted to an average specific gravity (see footnote 5 of the table). The adjusted values were then assumed to be directly comparable with the average values for the straight-grained poles.

The significant comparison is thus between the adjusted modulus of rupture found for the tested spiral grain poles, and the average modulus of rupture of 30-foot straight-grained poles as given in the ASTM report. This comparison may be conveniently expressed as a ratio, and it is so given in the last line of the table. The ratios provide an indication of the possible effect of slope and direction of spiral grain. This limited study did not precisely measure this effect, but did suggest a trend.

The ratios indicate, as might be expected, that straight-grained poles are stronger than those with a pronounced slope of grain. More significantly, however, the ratios show that right spiral-grained poles are nearly as strong as straight-grained poles and that left spiral-grained poles are only about half as strong as straight-grained poles. Since this result was evident in both species, it can be considered to indicate a definite trend in spiral-grained poles.

The results of the tests on the two left-spiraled Douglas-fir poles are believed to reflect some effects of knots. The knots may partially explain the low strength ratios of these poles. In pole 9, four 3/4- to 1-inch knots were present at the principal failure point, 16 feet from the butt end. Pole 4 had six to eight small knots (3/4- to $1\frac{1}{4}$-inch) per foot at the groundline area, where failure occurred 8 feet from the butt end. These knots were well within the limits permitted by the American Standards Association pole specifications (2). Four other poles had knots at failure points.

Table 5.--Strength and related properties of untreated spiral-grained Douglas-fir and western larch poles

Item	Douglas-fir					Western larch				
Pole no.	46	16	22	9	4	19	14	13	1	2
Spiral direction	R	R	R	L	L	R	R	R	L	L
Slope of grain	1:11	1:6	1:8	1:8	1:8	1:18	1:6	1:6	1:12	1:8
Class and length:										
As received	3-40	3-40	3-45	3-40	2-40	3-45	1-45	2-45	2-45	3-45
As tested[1]	3-35	3-35	3-35	3-35	2-35	2-35	1-35	1-35	1-35	2-35
Moisture content (percent):[2]										
At 1 inch	32	25	24	23	25	29	27	26	28	31
At 2 inches	21	22	20	21	22	23	24	22	23	23
Specific gravity[3]	.444	.446	.458	.483	.469	.475	.414	.438	.569	.540
Weight of pole (lb.)	783	888	915	840	940	935	1,108	956	1,298	983
At tip support	353	417	445	380	418	476	528	452	640	451
At butt support	430	471	470	460	522	459	580	504	658	532
Circumference of pole (in.):										
At tip	28.8	31.4	30.2	29.2	27.8	30.6	33.0	30.2	33.5	27.6
At butt	37.8	39.6	39.6	38.0	40.7	38.8	43.8	41.6	40.9	38.9
At load point[4]	35.2	37.0	37.4	36.7	38.7	36.8	42.6	39.2	40.1	37.5
Tip reaction (lb.)[5]	3,150	3,375	2,905	1,835	1,970	3,450	4,235	2,750	3,585	2,525
Deflection at midlength (in.)[5]	20.3	15.7	13.9	9.6	13.0	19.1	13.6	12.4	8.1	13.3
Modulus of elasticity (1,000 p.s.i.)	1,605	1,495	1,465	1,216	1,243	1,603	1,248	1,098	1,776	1,350
Modulus of rupture:										
At load point (p.s.i.)	7,770	7,150	6,010	4,020	3,710	7,560	5,870	4,940	6,020	5,240
Adjusted (p.s.i.)[6]	8,540	7,800	6,300	3,900	3,750	8,620	8,240	6,370	5,250	4,940
Ratio[7]	1.03	.94	.76	.47	.45	1.00	.95	.74	.61	.57

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[1] Tested as a 35-foot pole over a span of 33 feet with groundline 6 feet from butt end.

[2] Average of 3 moisture meter readings at the indicated depths below the pole surface near the load point.

[3] Values for computation based on green volume and ovendry weight.

[4] At groundline 5 feet from butt support and 28 feet from tip support.

[5] Under maximum superimposed load.

[6] Adjusted to average specific gravity of untreated 30-foot poles in the 1960 ASTM report (.473 for Douglas-fir and .519 for western larch.

[7] Ratio of adjusted modulus of rupture to average modulus of rupture of 30-foot poles in 1960 ASTM report (8,260 p.s.i. for Douglas-fir and 8,590 p.s.i. for western larch.

CONCLUSIONS

The results of this study indicate that spiral grain is an important variable that affects not only the twisting of poles in service but also their bending strength. The analysis of the study data showed that degree of seasoning, direction of grain slope, and steepness of grain slope had a significant influence on the twisting of the poles. The data on internal spiral grain show the spirality pattern to be one of initial left spiral grain, a gradual decrease to the zero axis, and finally, an increasing right spiral. Previous observations had indicated a lack of uniformity in the slope of grain of individual growth rings; these observations were confirmed in this study by measurements on two completely sectioned poles.

The data on maximum twist indicated that right spiral-grained poles have greater torsional stability than left spiral-grained poles. Examination of internal slope of grain indicates that the probable reason for the greater stability in right-spiraled poles is the counterbalancing of moisture shrinkage stresses. Practically all the poles with right spiral grain on the surface had internal left spiral grain. Thus, the shrinkage stresses tended to counteract each other and the pole twisted in the direction of the dominant stress. On the other hand, poles with left spiral grain on the surface contained only left-sloping grain, and hence were free to twist to the left without restraint. The greater stability of the right-spiraled poles indicates a possible basis for revising the present American Standards Association pole specifications, to make such poles acceptable.

The degree of slope of grain was also shown to have significant effect on the twisting of poles. Poles with a steep slope of grain twisted more than poles with a moderate slope of grain, regardless of spiral direction.

The twisting of poles was shown to be the result of moisture loss or seasoning of the poles while in the test. This indicates that proper preliminary seasoning of the poles to a moisture content in equilibrium with use conditions would probably eliminate the twisting of poles in service or reduce it to within tolerable limits. There is great need for a process or method that will dry poles faster than air seasoning.

Tree species was not found to be a significant factor. Spiral grain had the same effect in the three species studied and probably affects all species used for poles in much the same way. The data on tack displacement in this study indicate that poles twist along their entire length, but maximum displacement occurs at the top of the pole. The wood products industry needs a nondestructive way of sampling and determining internal spiral grain and a method of relating these measurements to pole performance.

The results of the limited study of internal spiral grain indicate that we should further investigate the causes of both radial and longitudinal variation. Earlier studies suggested that it might be possible to control or regulate spiral grain through silvicultural and management practices that influence growth rate. Also, the great emphasis placed on wood quality within recent years establishes the need for understanding spiral grain and its effect on wood products other than poles.

All the poles used in this study would be acceptable under present American Standards Association specifications. However, the data from the strength tests indicate that severely left-spiraled poles have lower bending strength and twist more than do severely right-spiraled poles. Table 5 shows that moderate right-spiraled grain with a slope of 1:12 or more has a negligible effect on the strength of a pole, and poles with a right spiral grain of 1:8 or less may have 75 percent of the strength of straight-grained poles. Poles with left spiral grain of 1:8 to 1:12 slope may not be more than 50 to 60 percent as strong as comparable straight-grained poles. Additional tests of poles of these and other species having moderate-to-steep slopes of grain are needed before the effects of spirality on strength can be definitely determined.

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